USER'S MANUAL

for

CABLE

- A Three-Dimensional, Finite-Segment Computer Code for Submerged and Partially Submerged Cable Systems

James W. Kamman
Research Associate

and

Ronald L. Huston
Professor of Mechanics

Department of Mechanical and Industrial Engineering
University of Cincinnati
Cincinnati, Ohio 45221

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I. SUMMARY

This is a User's Manual for the computer program UCIN-CABLE II. The program is designed to study the three dimensional dynamics of submerged and partially submerged towing cables. The cables themselves may have multiple branches. Figure 1. shows a schematic illustration of a typical

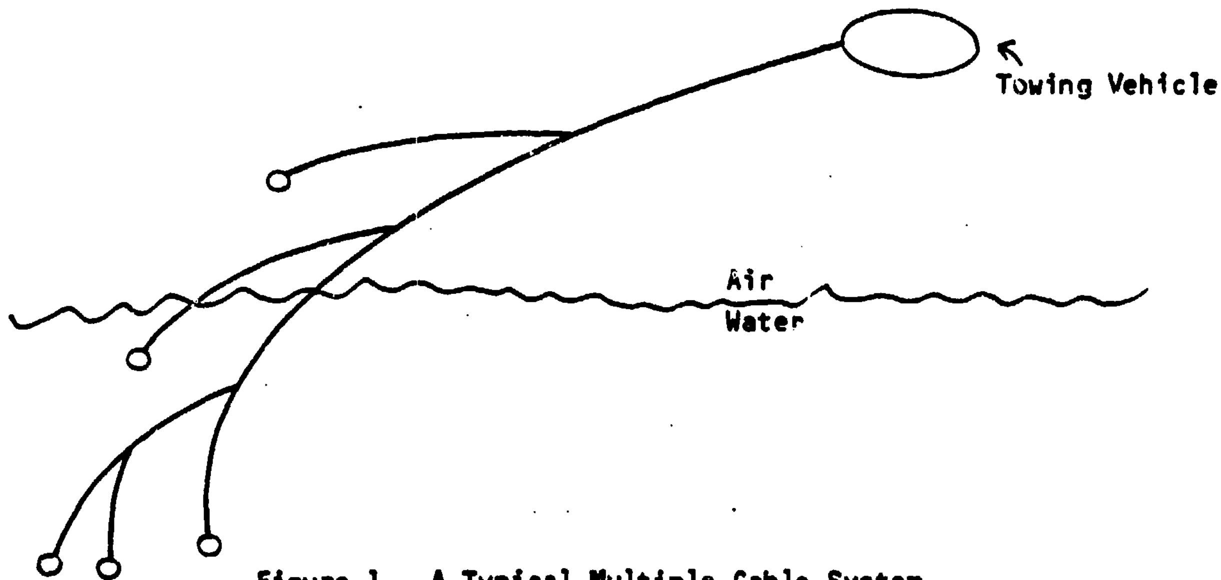

Figure 1. A Typical Multiple Cable System.

cable system. The system can of course be much simpler than that shown in Figure 1. For example, it could consist of a single cable segment as with a buoy or balloon mooring system as depicted in Figure 2.

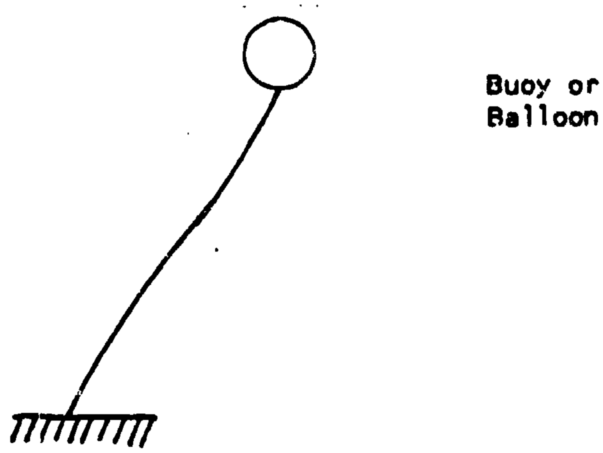

Figure 2. A Simple Mooring System

I. Summary

The manual provides instruction for using CABLE to study such cable systems. It also provides sample input and output data. The computer program itself is written in FORTRAN. Hence, the input requirements are in the FORTRAN format.

II. CAPABILITIES OF CABLE

CABLE is designed to perform the following dynamic analyses: Given: a) the physical data of the cable (weight, diameter, length) and the physical data of the towed body; b) the configuration of the cable branches; c) the fluid properties; d) the motion of the towed end of the cable; and e) the initial configuration of the cable system; then the program determines the kinematics (position, velocity, and acceleration) at the various points of the cable system as well as the cable tension.

CABLE provides the user with the following options:

1) Either English or metric units may be used.

2) A two- or three-dimensional analysis may be selected.

3) The cable system may be immersed in two fluid media - normally air and water.

4) The fluid media may be given a uniform "stream" velocity.

5) Fluid forces may be applied to the cable system. These forces include:
   a) Normal drag forces
   b) Tangential drag forces
   c) Added mass forces due to cable acceleration
   d) Bouyancy forces

   These fluid forces may be partially or totally neglected.

6) The towed end of the cable may have arbitrary motion relative to a ship frame. The ship frame itself may have motion in a plane.

7) Gravity forces may be included or neglected.

II. Capabilities of CABLE

In addition to the above options, the user may arbitrarily select the numerical integration parameters. Certain output options are also available.

III. THEORETICAL BASIS OF CABLE

The cable system is modelled by a series of cylindrical links. These links are connected in a chain to simulate the cable. Figure 3. depicts such a modelling. The number of links and hence their length, is a user option.

Figure 3. A Finite-Segment Model of a Cable.

The model of Figure 3. is a "finite-segment" model of the cable. As such it forms a "general-chain" system or an "open-tree" system. References [1-3]* provide an analytical basis for studying these systems. The governing differential equations are obtained using Lagrange's form of d'Alembert's principle and Kane's equations as exposited by Kane and others [4-8]. This procedure has distinct advantages over Newton's laws and Lagrange's equations for analyzing multibody systems. Specifically, Kane's method provides for the automatic elimination of non-working internal constraint forces while avoiding the tedious differentiation of scalar energy functions.

In the formulation of CABLE the velocities and accelerations are computed through vector derivatives which may be evaluated through vector cross products. This leads to algorithms which are readily converted into computer subroutines.

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* Numbers in brackets refer to References at the end of the manual.

III. Theoretical Basis of CABLE

The fluid forces are computed using the procedures outlined in References [9,10]. These include inertia ("added mass"), drag (normal and tangential), and hydrostatic (buoyancy) forces. They are represented on the cable links by forces passing through the centers of the links together with couples.

Finally, the governing equations are solved using RKGS [11], a fourth-order Runge-Kutta numerical integrator. CABLE is written, however, so that other numerical integrators may also be used.

IV. DEFINITIONS OF TERMS

This part of the Manual defines the terminology used in CABLE. These definitions are useful in understanding the input requirements. Underlining is used to further identify terms of interest.

1. Cable Model

Figure 4. shows a finite-segment cable model of a cable system.

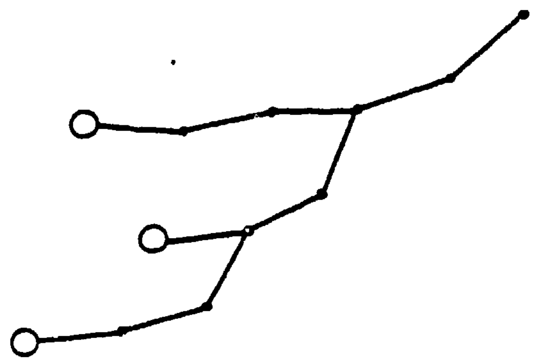

Figure 4. A Finite-Segment Model of a Cable System.

It consists of a series of cylindrical cable links connected in "tree-like" fashion such that no closed loops are formed.

2. Cable Link System

A cable link system is a set of connected cable links together with the towed bodies as shown in Figure 4. Thus, a cable link system is a multibody system as defined in References [2,3].

3. Cable Link

A cable link is an individual member of a cable link system (aside from towed bodies). A cable link is a rigid cylindrical rod. It is connected to adjacent links and the towed bodies by either spherical or hinge joints.

IV. Definitions of Terms

4. Reference Links and Reference Points

The uppermost link of a cable link system is called the reference link as shown in Figure 5. The upper end of the reference link is called the system reference point Q. In a typical dynamic configuration of the system, Q is given a prescribed motion relative to the mean ship frame (See 7. below.).

Also, each of the links of the cable link systems has its own reference point. For the reference link, it is Q the system reference point. For any other link, say L_k, it is Q_k the joint location at the upper end of the link as shown in Figure 5.

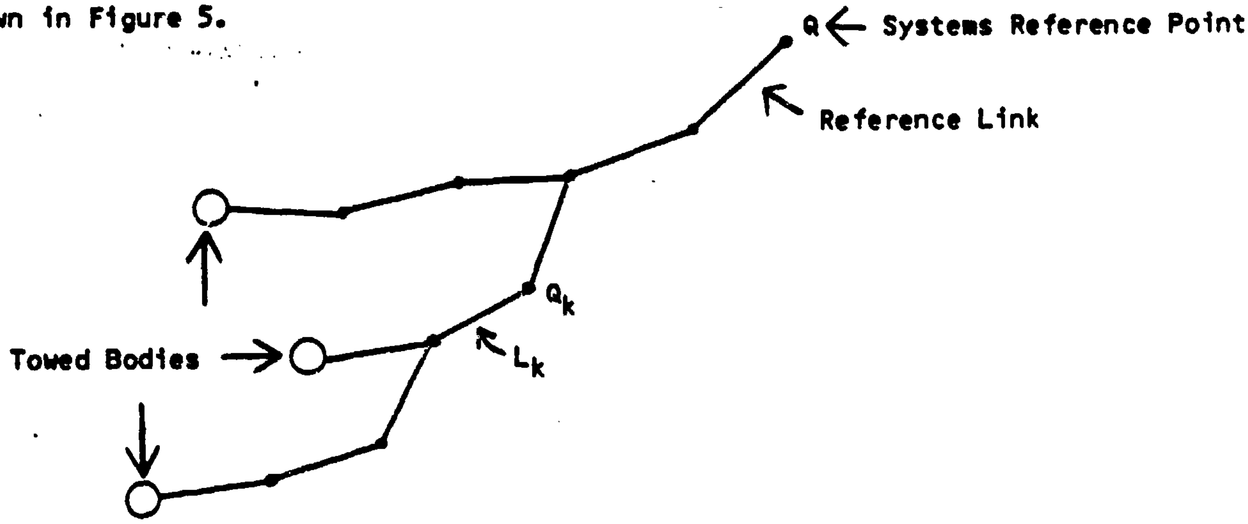

Figure 5. Reference Link, Reference Point, and Towed Bodies

5. Towed Bodies

Currently in CABLE there is provision for towed spherical bodies at the ends of the branches of the cable system. These bodies are referred to as the towed spheres. The towed spheres are attached to the cable links by by either a spheri.-l or hinge joint at the center of the sphere.

6. Link Connection Array

The configuration of the cable link system and the arrangement of the branches can be described by a link connection array. To develop this array, let the links of the system be numbered as follows: Let the reference link be link 1, called L_1. Next, number the remaining links and towed spheres in ascending progression away from L_1 through the branches of the system. Finally, let the mean ship frame be body 0, called L_0. Figure 6. illustrates this numbering procedure for the cable system of Figures 4. and 5.

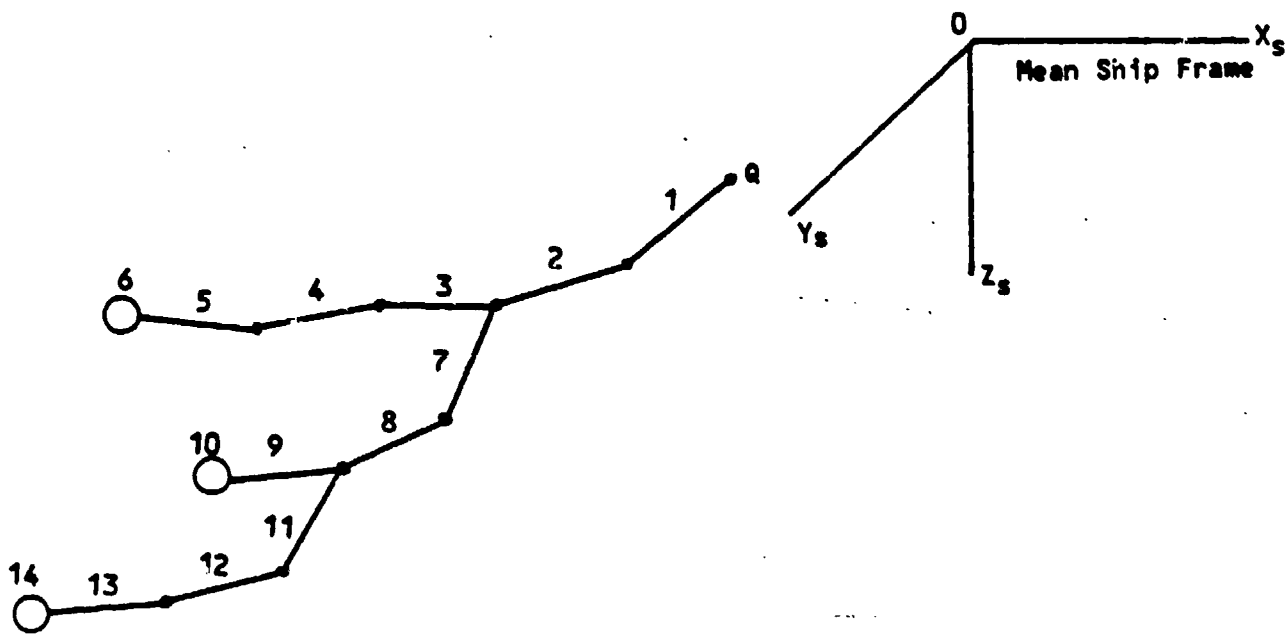

Figure 6. Numbering of the Cable Link System of Figures 4. and 5.

If the links and towed spheres are numbered in this manner, each link and sphere, except the reference link, is connected to one and only one adjacent lower numbered link. (Note, however, that a link, for example, L_2 may be connected to more than one adjacent higher numbered link.)

The array listing the lower numbered links is called the link connection array. For the system shown in Figure 6. this array is:

Link/Sphere:	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Array:	0	1	2	3	4	5	2	7	8	9	8	11	12	13

Note that the configuration of the system can be constructed once the link connection array is known. That is, there is an equivalence between the cable system configuration and the connection array.

7. Mean Ship Frame, Inertia Frame, and Coordinate Systems

In CABLE the reference point Q at the upper end of the reference link may be given an arbitrary prescribed motion relative to a mean ship frame which itself may be given a prescribed motion relative to an inertial reference frame. This is depicted in Figure 7. The mean ship frame is assumed

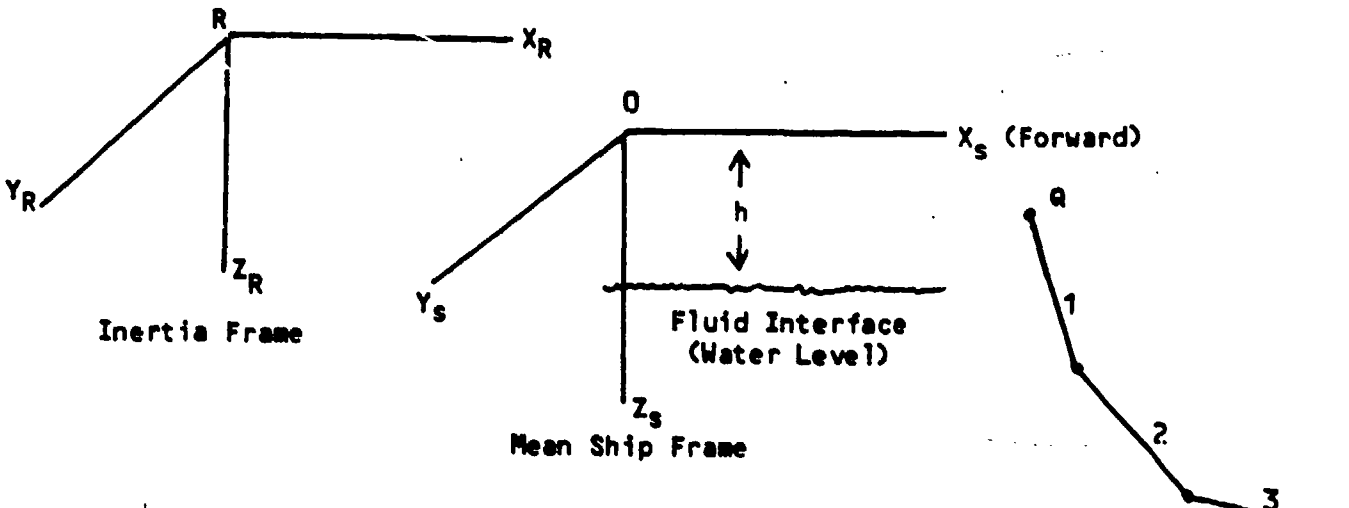

Figure 7. Inertia Frame, Mean Ship Frame and Coordinate Systems.

to be rigidly attached to a towing vessel such as a ship or helicopter.

Coordinate systems are associated with both the inertia frame and the mean ship frame as shown in Figure 7. In the mean ship frame the X_S direction is forward, Z_S is vertically down and Y_S is in the starboard direction. Although the motion of Q relative to the mean ship frame may be arbitrarily specified, the motion of the mean ship frame relative to the inertia frame is restricted to motion along X_S and rotation (steering) about Z_S.

Finally, CABLE has the option of locating the mean ship frame at at elevation h (which could be negative) above a fluid interface or water level.

8. Acceleration Profiles

The specification of the motion of reference point Q relative to the mean ship frame and the motion of the mean ship frame relative to the inertia frame (See Figure 7.) may be accomplished either by using an acceleration profile, described here, or by using a precoded function, described in the following section.

An acceleration profile is simply a set of data representing the coordinates of selected points of an acceleration-time curve. Such coordinates may be obtained from the graph of the acceleration function.

CABLE has the capability of accepting as many as 25 data points from an acceleration curve. A piecewise linear approximation is then made of the acceleration function. For example, consider the acceleration function and its approximation shown in Figure 8. The acceleration, velocity, and displacement during the i^{th} time interval are then:

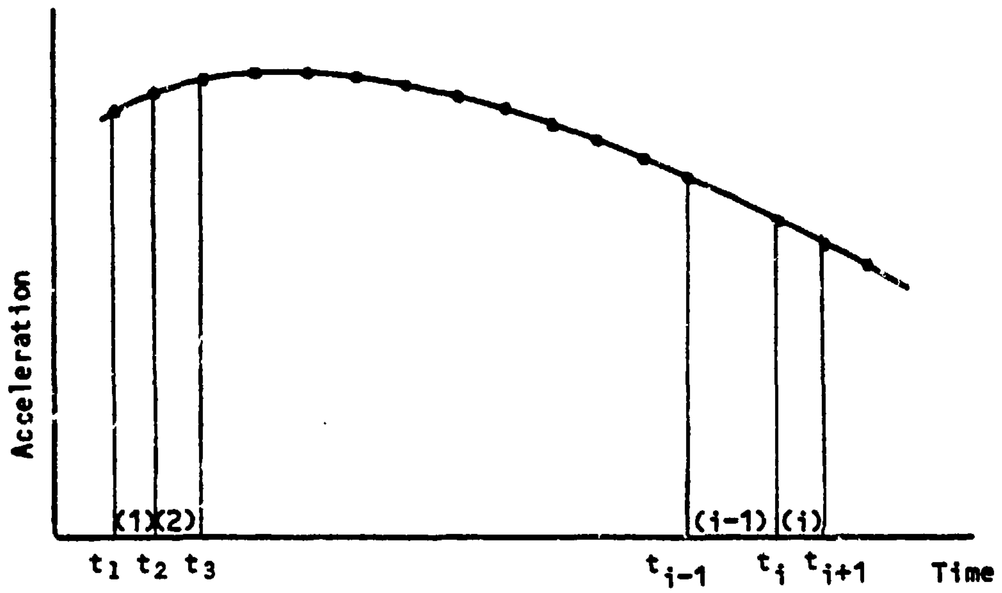

Figure 8. Acceleration Profile Approximation

$$a = a_i + \left(\frac{a_{i+1} - a_i}{t_{i+1} - t_i}\right)(t - t_i) \tag{1}$$

$$v = v_i + a_i\,(t - t_i) + \left(\frac{a_{i+1} - a_i}{t_{i+1} - t_i}\right)(t - t_i)^2/2 \tag{2}$$

and

$$d = d_i + v_i(t - t_i) + a_i(t - t_i)^2/2 + \left(\frac{a_{i+1} - a_i}{t_{i+1} - t_i}\right)(t - t_i)^3/6 \tag{3}$$

where a_i, v_i, d_i, and t_i are the acceleration, velocity, displacement, and time at the beginning of the i^{th} interval. Thus, the entire kinematic profile (displacement, velocity, and acceleration) is known when the a_i are given and when v_1 and d_1, the initial velocity and displacement (at time t_1), are given.

9. Precoded Functions

If the motion of reference point Q relative to the mean ship frame or if the motion of the mean ship frame relative to the inertia frame is relatively simple, it may be convenient to describe the motion using a precoded function. For example, these functions may be used to describe constant or decaying sinusoidal speed of the mean ship frame. Specifially, CABLE provides the user with the following precoded function:

$$f = f_0 + Ae^{bt} \cos(pt + \phi) \qquad (4)$$

where f_0, A, b, p, and ϕ are user supplied constants. Hence, for a constant ship speed, the user would simply provide a value for f_0 with the other values being zero (which are the default values). Specific input format is discussed in the following part of the Manual.

10. Fluid Velocities

CABLE also has the provision of allowing each of the fluids to have a uniform (constant in time and space) "stream" velocity. Specific input format is described in the following part of the Manual.

11. Link Orientation Angles

The relative orientation of two adjacent links can be defined in terms of their relative orientation angles as follows: Consider a typical cable link L_k as shown in Figure 9. Let X_k, Y_k, and Z_k represent a coordinate

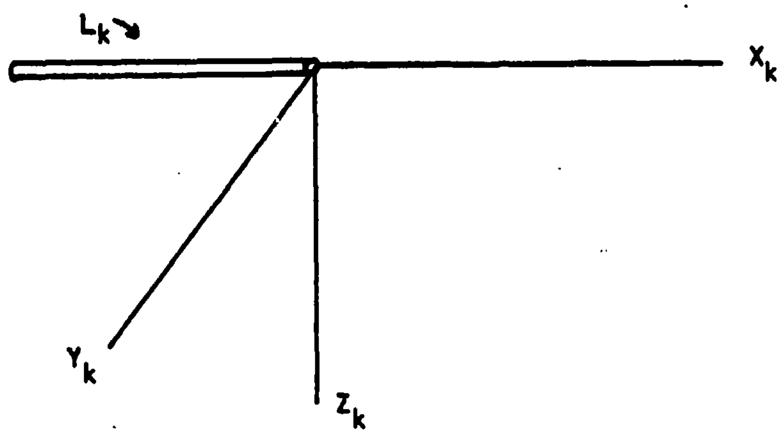

Figure 9. Typical Link L_k and Coordinate Axes.

IV. Definitions of Terms

frame attached to L_k such that the axis of L_k is along X_k as shown. Next, consider link L_k and its adjacent lower numbered link L_j as shown in Figure 10. Let the axes system X_j, Y_j, and Z_j of L_j be initially aligned

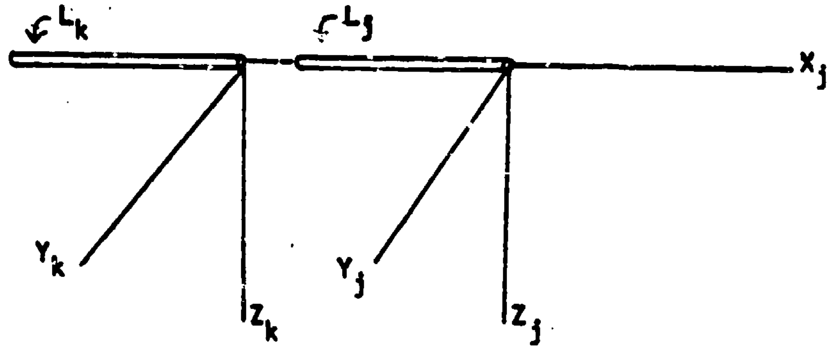

Figure 10. Two Typical Adjoining Links and Aligned Axes Systems.

with the axes system of L_k as shown. Now, L_k can be brought into a general orientation relative to L_j by three successive rotations through angles γ_k, α_k, and β_k about axes Z_k, X_k, and Y_k. These angles are taken as positive when the rotation is "right-handed" or dextral relative to the axis. They are thus sometimes called "dextral" orientation angles. For example, a positive γ_k rotation is shown in Figure 11.

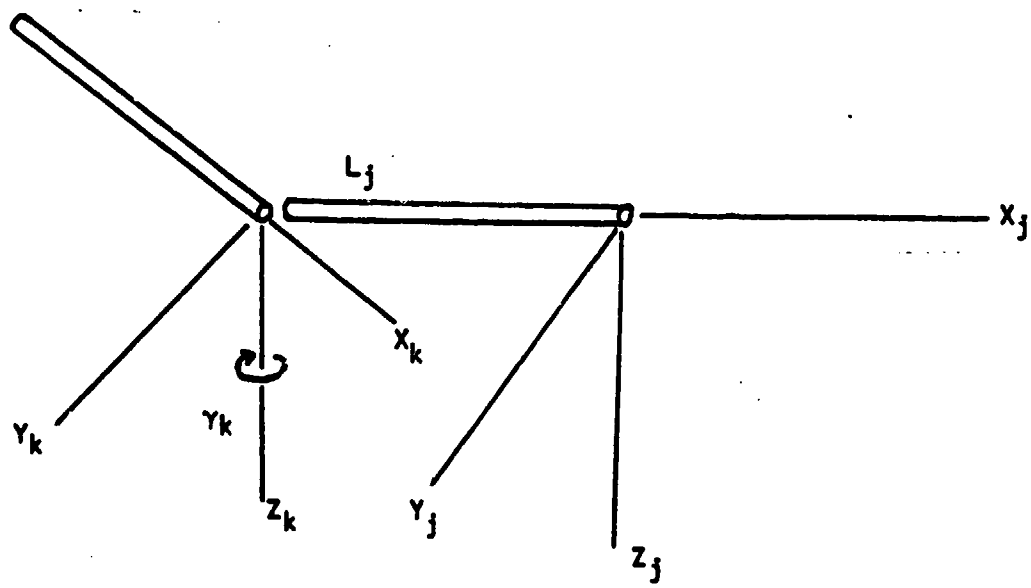

Figure 11. Positive γ_k Rotation.

IV. Definitions of Terms

Note that the angles γ_k, α_k, and β_k are defined in terms of rotation of L_k about the Z_k, X_k, and Y_k axes (as opposed to rotations about Z_j, X_j, and Y_j). This means that if $\gamma_k \neq 0$, α_k is the rotation of L_k about the "rotated" X_k axis as shown in Figure 12. β_k is defined similarly as a rotation about the rotated Y_k axis.

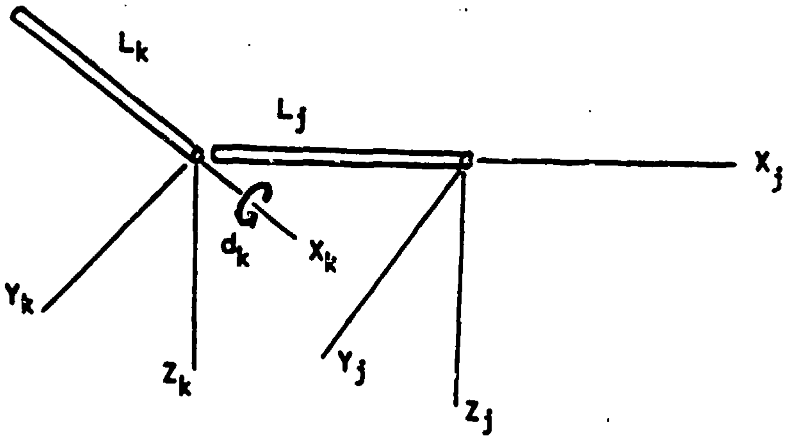

Figure 12. Positive α_k Rotation

The reason for the ordering γ_k, α_k, β_k (as opposed to say α_k, β_k, γ_k) is to have the "middle" rotation (that is, α_k) to be about the cable link axis. This middle rotation is then a measure of the cable "twist." Assuming that the twist between adjacent links is relatively small (specifically, less than 90°), this ordering (γ_k, α_k, β_k) avoids orientation singularities as discussed in Reference [12].

12. Initial Cable Configuration

The initial configuration of the cable system before the equations of motion are integrated, depends upon the initial values of the relative orientation angles of the links and their derivatives. For example, if the initial values of all the orientation angles are zero, the initial configuration of a single branch cable system would be as shown in Figure 13.

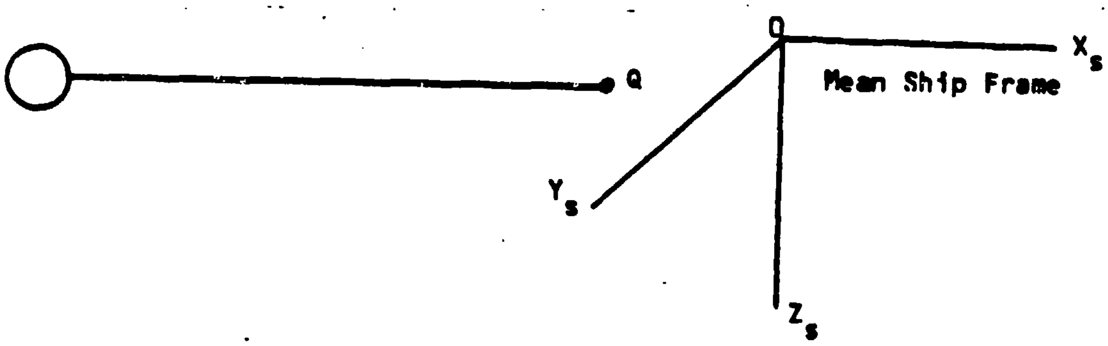

Figure 13. "Zero" Initial Configuration of a Single Branch Cable.

IV. Definitions of Terms

13. Two and Three Dimensional Analyses

CABLE has been developed to provide a three-dimensional analysis of cable dynamics. However, there are many cases of interest where the cable moves nearly in a plane. To accomodate these cases, CABLE has a two-dimensional analysis option.

14. Spherical and Hinge Connecting Joints

If the cable has three dimensional motion, the cable links are connected to each other by spherical (that is, "ball-and-socket") joints. When the motion is restricted to a plane as in the two-dimensional option, the cable links are connected to each other by pin (that is, "hinge") joints. In this latter case, only one of the three orientation angles (β_k) is needed to define the orientation of a typical link.

15. Weight Density, Link Length and Link Diameter

The physical parameters needed by CABLE to describe the cable links are the weight density, link length, and link diameter. The weight density is defined as the weight per unit length.

The cable links may have different lengths, diameters, and weights. That is, the cable need not be uniform in its physical properties.

When the above data are given, CABLE automatically calculates the link mass center locations and the link inertia dyadics.

16. Weight and Diameter of the Towed Spheres

In addition to the link physical parameters, CABLE also requires the physical parameters of the towed spheres. These are simply the sphere weights and diameters.

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17. Fluid Forces

CABLE has the options of including up to four kinds of fluid forces exerted on the cable links: 1) drag forces normal to the link; 2) drag forces parallel (tangent) to the link; 3) "added-mass" forces; and 4) buoyancy forces. Reference [9] describes these forces in detail.

The drag forces and the added mass forces may be defined as follows: Consider a typical cable link as shown in Figure 14. Let G_k be the center

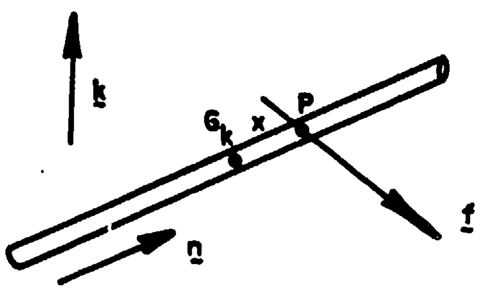

Figure 14. Fluid Force at a Typical Point of a Cable Link.

of the link and let P be a point a distance x from G_k as shown. The added mass and drag forces at P may then be represented as:

$$\underset{\sim}{f} = A\underset{\sim}{a}_N + B|\underset{\sim}{v}_N|\underset{\sim}{v}_N| + C|\underset{\sim}{v}_T|\underset{\sim}{v}_T \qquad (5)$$

where $\underset{\sim}{v}_N$ is the normal component of the fluid velocity relative to the cable link at P, and the coefficients A, B, and C are:

$$A = C_M\rho(\pi/4)d^2 \qquad (6)$$

$$B = C_N\rho(d/2) \qquad (7)$$

$$C = C_T\rho(d/2) \qquad (8)$$

IV. Definitions of Terms

where ρ is the fluid mass density and d is the diameter of the cable link. C_M, C_N, and C_T are coefficients dependent upon the Reynolds number of the fluid flow past the cable link. These coefficients are usually determined experimentally. In CABLE the following values are used [9,13]:

$$C_M = 1.0 \tag{9}$$

$$C_N = \begin{cases} 0.0 \text{ for } Re_N \leq 0.1 \\ 0.45 + 5.93/(Re_N)^{0.33} \text{ for } 0.1 < Re_N \leq 400.0 \\ 1.27 \text{ for } 400. < Re_N \leq 10^5 \\ 0.3 \text{ for } Re_N > 10^5 \end{cases} \tag{10}$$

$$C_T = \begin{cases} 0.0 \text{ for } Re_T \leq 0.1 \\ 1.88/(Re_T)^{0.74} \text{ for } 0.1 < Re_T \leq 100.55 \\ 0.062 \text{ for } Re_T > 100.55 \end{cases} \tag{11}$$

where the Reynolds numbers Re_N and Re_T are defined as

$$Re_N = \rho d|\underset{\sim}{v}_N|/\mu \tag{12}$$

and

$$Re_T = \rho d|\underset{\sim}{v}_T|/\mu \tag{13}$$

where μ is the fluid viscosity.

In Equation (5) the first term is called the "added-mass" force, the second term is called the "normal drag" force, and the third term is called the "tangential drag" force. In CABLE the system of added mass and drag forces acting at all the points of the cable link are replaced by a single force passing through G_k together with a couple. For additional information, see References [9,13].

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The buoyancy forces are due to the hydrostatic pressure forces exerted on the cable link. These forces are normal to the surfaces of the link which is exposed to the fluid. Since the ends of the cable link are not exposed to the fluid the resultant hydrostatic force on the link is normal to the link axis. Hence, the system of hydrostatic forces may be replaced by a single force $\underset{\sim}{B}_N$ normal to the link axis given by:

$$\underset{\sim}{B}_N = -\rho g v_k \underset{\sim}{n} \times (\underset{\sim}{k} \times \underset{\sim}{n}) \tag{14}$$

where ρ is the fluid mass density, g is the gravity constant, v_k is the cable link volume, $\underset{\sim}{n}$ is a unit vector along the link axis, and $\underset{\sim}{k}$ is a vertical unit vector as shown in Figure 14. (For additional information, see Reference [9].)

The fluid forces on the towed spheres are obtained similarly. See Reference [9].

18. Weight Forces

The weight forces may be represented on each cable link L_k by a single vertical (downward) force $\underset{\sim}{W}_k$ passing through the mass center G_k of L_k. If γ_k is the weight density per unit length of L_k, $\underset{\sim}{W}_k$ may be expressed as:

$$\underset{\sim}{W}_k = -\gamma_k \ell_k \underset{\sim}{k} \tag{15}$$

where ℓ_k is the length of L_k and where $\underset{\sim}{k}$ is the vertical unit vector shown in Figure 14.

Similarly, the weight forces on the towed spheres may be represented by single vertical forces passing through the center of the spheres with magnitude equal to the sphere weight.

19. Units

CABLE allows the user to select either English or metric units for the input and output data. If English units are selected the units are slugs, feet, and seconds for mass, length, and time. However, inches are used for the link diameter and towed sphere diameter. If metric units are selected the units are kilograms, meters, and seconds with centimeters used for link diameter and towed sphere diameter.

20. Labels

CABLE allows the user to arbitrarily label or name the links, their reference points, and the towed spheres.

V. INPUT DATA

This part of the Manual describes the specific input data requirements of CABLE. The data itself is described in terms of "line images" such as would also appear on a computer card.

As noted earlier, the algorithms and code of CABLE are written in FORTRAN. Hence, the input data is to be submitted in the FORTRAN format. Integer data is to be entered in I5 format and real data in either F10.4 or E10.4 unless otherwise specified. The order of the input data is in the same order as it is described below. The units of the input data are either English or metric according to the option selected.

1. Heading or Title

The first line of input to CABLE contains a title which may be used to identify the particular data entered. It may contain up to 80 characters, and it will appear at the top of each computer output data page.

2. Options

CABLE has a number of user options to define the desired analysis. These options are selected by specifying integer values (usually 0,1,2,3,4, or 5) as follows:

1) Units (See Section 19., Part IV): On the first line of the data enter a 1 if English units are desired. Enter a 2 if metric units are desired.

2) Two or three dimensional analysis (See Section 13., Part IV): Next, enter a 2 if a two-dimensional analysis is desired. Enter a 3 if a three-dimensional analysis is desired.

3) Normal drag forces (See Section 17., Part IV): Enter a 1 to include these forces. Enter a 0 to neglect these forces.

4) Tangential drag forces (See Section 17., Part IV): Enter a 1 to include these forces. Enter a 0 to neglect these forces.

5) Added mass forces (See Section 17., Part IV): Enter a 1 to include these forces. Enter a 0 to neglect these forces.

6) Bouyancy forces (See Section 17., Part IV): Enter a 1 to include these forces. Enter a 0 to neglect these forces.

7) Gravity forces: Enter a 1 to include these forces. Enter a 0 to neglect these forces.

8) Viscoscities and fluid mass densities (See Section 17., Part IV): Enter a 0 to use the default values coded in CABLE. See Table I. If values different from these default values are desired, enter a 1. Then four lines of data must be entered, providing the following:

i) Viscoscity of the first fluid (usually air) (lb.sec./ft^2 or N.sec./m^2).

ii) Mass density of the first fluid (slug/ft^3 or kg/m^3).

	English	Metric
Viscosity (air)	3.7188×10^{-7}(lb-sec)/ft^2	1.7802×10^{-5}(N-sec)/m^2
Mass Density (air)	2.378×10^{-3} slug/ft^3	1.2252 kg/m^3
Viscosity (water)	3.516×10^{-5}(lb-sec)/ft^2	1.6831×10^{-3}(N-sec)/m^2
Mass Density (water)	1.9856 slug/ft^3	1.0231×10^3 kg/m^3

TABLE I. Default Values for Fluid Viscoseities and Mass Densities

iii) Viscoscity of the second fluid (usually water) (lb.sec./ft^3 or N.sec/m^2).

iv) Mass density of the second fluid (slug/ft^3 or kg/m^3).

9) Fluid velocities: CABLE has the option of allowing the fluids to have constant stream velocities in any direction. To use this option enter a 1. Next, enter two lines of data providing: the X, Y, and Z components relative to inertia space of the velocities of the two fluids (fluid 1 (air) on the first line and fluid 2 (water) on the second line).

To decline this option, enter a 0. This means the fluids will have zero velocity.

10) Fluid Interface Level: CABLE has the option of allowing the fluid interface level (that is, the water level) to be located at some nonzero vertical distance below the mean ship frame. To use this option enter a 1. Then on the next line of input, enter the vertical distance (positive downward) from the mean ship frame. To decline this option enter a 0. This means the fluid interface and the mean ship frame will be on the same level.

The set of options data will consume between 10 and 17 lines, depending upon whether viscoscities, densities, velocities, and the fluid interface level are specified by the user.

3. Number of Links

Following the input on user options, enter the number of cable links on a single line.

V. Input Data

4. Individual Link Data

The next input data is a series of data sets describing the physical and geometrical properties of each link, as follows:

1) Link number (See Section 6., Part IV).

2) Label: Any name up to 20 characters in length.

3) Link Reference Point Label (or "joint" label) (See Section 4., Part IV): Any name up to 20 characters in length.

4) Link number of adjacent lower numbered link.

5) Link weight density (weight per unit length, lb/ft or N/m).

6) Link length (ft or m).

7) Link diameter (in or cm).

8) Initial configuration of the link. This line will generally contain three numbers representing γ, α, and β the initial angles (in degrees) of the link. (See Sections 11. and 12., Part IV).

   If the two-dimensional analysis is selected, only one initial link angle, β, is entered.

9) Initial motion of the link. This line will generally contain three numbers representing $\dot{\gamma}$, $\dot{\alpha}$, and $\dot{\beta}$ the derivatives of the initial angles of the link (in degrees/second). If the two-dimensional analysis is selected, only one initial link angle derivative, $\dot{\beta}$, is entered.

Nine lines of data are required for each link.

V. Input Data

5. Number of Towed Spheres

The link data is followed by analogous data for the towed spheres. The first line of towed sphere data contains the number of towed spheres.

6. Individual Towed Sphere Data

The next input data is a series of data sets describing the physical and geometrical properties of each towed sphere as follows:

1) Towed sphere number (See Section 6., Part IV).

2) Towed sphere label (up to 20 characters).

3) Link number of the adjacent towing link.

4) Towed sphere weight (lb or N).

5) Towed sphere diameter (in or cm).

Five lines of data are required for each towed sphere.

7. Motion of the Mean Ship Frame and the System Reference Point

The mean ship frame may have planar motion relative to the inertia frame R. Two variables representing the forward (or reverse) speed and the turning angle are used to describe this motion. Also, the system reference point Q may have arbitrary motion relative to the mean ship frame, requiring an additional three variables. (See Section 7., Part IV.)

For the input data these variables are identified by the following integers:

V. Input Data

1 - Forward displacement (x) of reference point Q relative to the mean ship frame.

2 - Starboard displacement (y) of reference point Q relative to the mean ship frame.

3 - Vertical (downward) displacement (z) of reference point Q relative to the mean ship frame.

4 - Forward (or reverse, if negative) speed of the mean ship frame relative to the inertia frame R. Note: If a precoded function is used to specify this motion, the mean ship frame is assumed to coincide with the inertial frame at t = 0.0.

5 - Turning angle of the mean ship frame relative to the inertia frame R. (The turning angle is positive for starboard turning.)

The data describing these variables may be specified in two ways: 1) by using precoded functions and 2) by using acceleration profiles. (See Sections 8. and 9., Part IV.) The precoded functions are of the form:

$$f = f_0 + Ae^{bt}\cos(pt + \phi) \tag{16}$$

where f_0, A, b, p, and ϕ are constants. The acceleration profiles are described in Section 8. of Part IV of the Manual.

The specific input data requirements are as follows: First, enter the number of these variables which are to have nonzero values during the motion. Then, for each of these variables enter its identifying integer (see above) in column 1. In column 2 enter a 1 or a 2 depending on whether a precoded function or an acceleration profile is desired.

V. Input Data

If a precoded function is selected, enter the values of f_0, A, b, p, and ϕ on the next line.

Alternatively, if an acceleration profile is selected, enter the number of data points (up to 25) on the next line. This line, in turn, must then be followed by the same number of data lines as there are data points (one line per point). The first of these lines contains: i) the initial time, ii) the initial acceleration, iii) the initial speed, and iv) the initial displacement. The subsequent lines contain two numbers: i) the time and ii) the acceleration value.

If several variables have specified motion, their data is included in serial fashion.

8. Integration Options

The next data is a set of four numbers setting the parameters of the integration subroutine RKGS. These numbers are entered on a single line as follows: i) Integration starting time, ii) Integration ending time, iii) Integration time increment, and iv) Upper bound on the error. Note: If the integration time increment is input as a negative value, say -I, then CABLE will automatically reset the increment to $(2)^{-I}$.

9. Output Options

1) The next line contains the time increment for printing the computed data. Since printing this data at each integration step can produce an excessive amount of printed output, the print time increment is usually greater than the integration time increment.

2) At the beginning of the output data, CABLE lists a copy (or "echo") of the input data. The extent of the listing of computed data is a user option. To exercise this option, enter an integer (0,1,2,3,4) in column 1 according to the following printing priority:

V. Input Data

0 - Prints all computed data: Position, velocity, and acceleration of the mean ship frame; Position, velocity, and acceleration of Q the system reference point; Orientation angles and their derivatives for each link (in degrees, degrees/second, and degrees/second/second); Position, velocity, and acceleration of the link and towed sphere mass centers relative to inertia space and relative to the mean ship frame; Position velocity, and acceleration of the connecting joints relative to the inertia space and relative to the mean ship frame; Cable tension at the system reference point Q; and Cable tension at the connecting joints.

1 - Prints as above for the option integer 0, except for the cable tension at the connecting joints.

2 - Prints as above for the option integer 1, except for the cable tension at the system reference point.

3 - Prints as above for the option integer 2, except for the position velocity, and acceleration of the joints.

4 - Prints as bove for the option integer 3, except for the position, velocity, and acceleration of the mass centers.

VI. EXAMPLE INPUT DATA

For an illustration of the input data consider the cable link system shown in Figure 15.

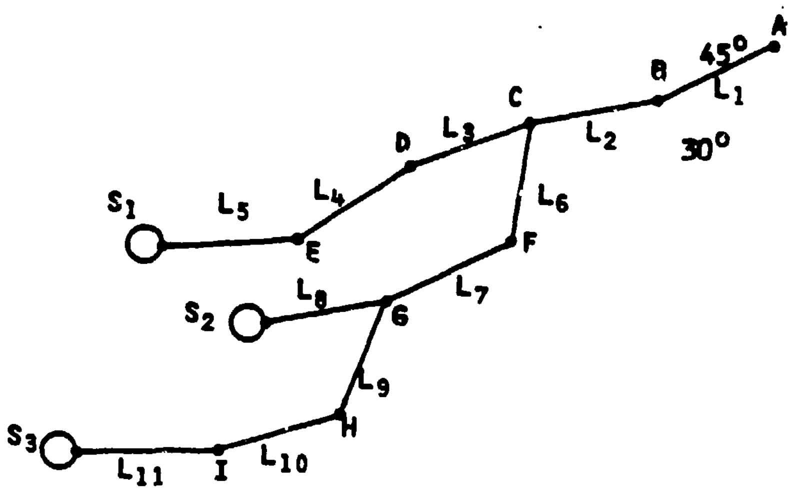

Figure 15. Example Cable System

Let the eleven cable links be identical having length 2 ft., diameter 0.25 in., and weight density of 0.2 lb./ft. Let the three towed spheres have diameters 1.0 in., 1.5 in. and 2.0 in. with weights of 0.5 ob., 1.688 lb., and 4.0 lb.

Let the mean ship frame have a forward motion defined by the acceleration profile shown in Figure 16. Let the initial forward ship spead be 5 ft/sec., and let the initial displacement be zero.

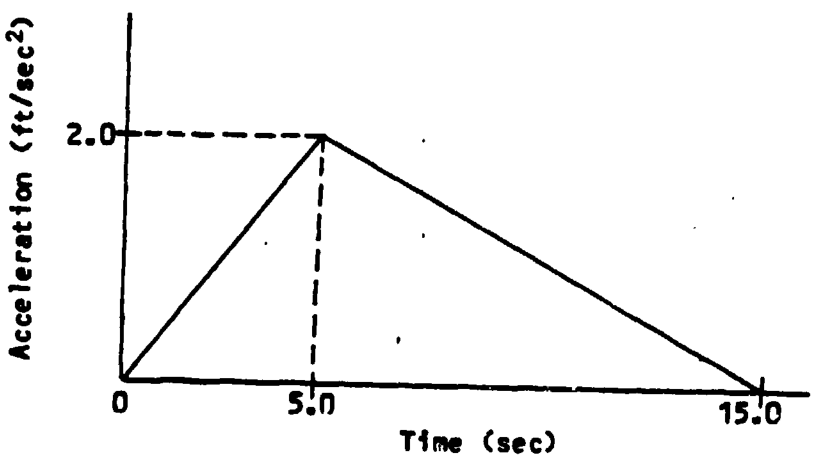

Figure 16. Acceleration Profile for Forward Mean Ship Frame Motion

Let the system reference point (point A) have oscillatory motion relative to the mean ship frame given by the expression

$$z = 0.5 \cos \pi t$$

Let the fluid level be 3 ft. below the mean ship frame.

Let the links, spheres, and joints be lebelled as shown in Figure 15.

Let the system be moving in still air and calm water. Let gravity and fluid forces be acting and let the air and water viscosities and densities be the same as the default values in CABLE.

Finally, to illustrate the input of initial conditions, let the initial configuration of the cable system be in the X-Z, plane. Let link 1 make an angle of 45° with the horizontal and let link 2 make an angle of 30° with link 1 as shown in Figure 15. Let the initial angles of all other links all be zero (even though they are not depicted that way in Figure 15.)

The input data for a three-dimensional analysis of the motion is then as follows: (Note: The comments in parentheses are for illustration only and should not appear in the normal FORTRAN input.)

```
Line Column Number
         1         2
123456789012345678901234...

EXAMPLE INPUT DATA

    1                                   (English Units)
    3                                   (3-D analysis)
    1                                   (include normal drag)
    1                                   (include tangential drag)
    1                                   (include added mass forces)
    1                                   (include buoyancy forces)
    1                                   (include gravity forces)
    0                                   (use default fluid properties)
    0                                   (fluids are at rest)
    1                                   (specify nonzero fluid interface
3.0                                     level)

         1         2
123456789012345678901234...
```

```
         1         2         3
123456789012345678901234...  0

   11                                                     (number of cable links)
    1                                                     (link body number)
L1                                                        (link label)
A                                                         (reference point label)
    0                                                     (lower link)
0.2                                                       (weight/length)
2.0                                                       (length)
0.25                                                      (diameter)
0.0        0.0        45.0                                (initial orientation)
0.0        0.0        0.0                                 (initial angle derivatives)
    2                                                     (next link body number and data)
L2
B
    1
0.2
2.0
0.25
0.0        0.0        -30.0
0.0        0.0        0.0
    3                                                     (next link body number and data)
L3
C
    2
0.2
2.0
0.25
0.0        0.0        0.0
0.0        0.0        0.0
    4                                                     (next link body number and data)
L4
D
    3
0.2
2.0
0.25
0.0        0.0        0.0
0.0        0.0        0.0

         1         2         3
123456789012345678901234...  0
```

```
Line Column Number
              1              2              3
12345678901234567890123 4...  0

      5                                     (next link body number and data)
L5
E
      4
0.2
2.0
0.25
0.0          0.0          0.0
0.0          0.0          0.9
      7                                     (next link body number and data)
L6
C
      2
0.2
2.0
0.25
0.0          0.0          0.0
0.0          0.0          0.0
      8                                     (next link body number and data)
L7
F
      7
0.2
2.0
0.25
0.0          0.0          0.0
0.0          0.0          0.0
      9                                     (next link body number and data)
L8
G
      8
0.2
2.0
0.25
0.0          0.0          0.0
0.0          0.0          0.0
              1              2              3
1234567890123456789012 34...  0
```

```
Line Column Number
          1         2         3
1234567890123456789012345...  0

   11
0.2
2.0
0.25
0.0       0.0       0.0
0.0       0.0       0.0
   13                                                       (next link body number and data)
L11
I
   12
0.2
2.0
0.25
0.0       0.0       0.0
0.0       0.0       0.0
    3                                                       (number of towed spheres)
    6                                                       (sphere body number)
S1                                                          (label)
    5                                                       (body number of lower link)
0.5                                                         (weight)
1.0                                                         (diameter)
   10                                                       (next spherical body number and data)
S2
    9
1.688
1.5
   14                                                       (next spherical body number and data)
S3
   13
4.0
2.0
    2                                                       (number of specified variables)
31                                                          (variable 3 is specified with a
0.0       0.5       0.0       3.1416    0.0                 precoded function)
42                                                          (variable 4 is specified with an
0.0       0.0       5.0       0.0                           acceleration profile)

          1         2       3
1234567890123456789012345...0
```

Line Column Number

```
         1         2         3
123456789012345678901234...  0

5.0      2.0
15.0     0.0
0.0      20.0      0.25      0.001          (integration parameters)
0.5                                         (time increment for printing data)
0                                           (output option--print all data)

         1         2         3
123456789012345678901234...  0
```

APPENDIX

SUMMARY OF INPUT DATA REQUIREMENTS

This Appendix to the Manual provides an abbreviated summary of the input data requirements for a quick reference.

1. Heading or Title: Heading of up to 80 characters.

2. Options: As follows:

   1) Units:

      Enter 1 for English units.
      Enter 2 for metric units.

   2) Two or three dimensional analysis:

      Enter 2 for two-dimensional analysis.
      Enter 3 for three-dimensional analysis.

   3) Normal drag forces:

      Enter 1 to include the forces.
      Enter 0 to neglect the forces.

   4) Tangential drag forces:

      Enter 1 to include the forces.
      Enter 0 to neglect the forces.

   5) Added mass forces:

      Enter 1 to include the forces.
      Enter 0 to neglect the forces.

   6) Buoyancy forces:

      Enter 1 to include the forces.
      Enter 0 to neglect the forces.

7) Gravity forces:

Enter 1 to include the forces.

Enter 0 to neglect the forces.

8) Viscoscities and fluid mass densities:

Enter 0 to use the default values.

Enter 1 to use substitute values entered on four subsequent data lines as follows:

i) Viscoscity of the first fluid

ii) Mass density of the first fluid

iii) Viscoscity of the second fluid

iv) Mass density of the second fluid

9) Fluid velocities:

Enter 0 for zero fluid velocities.

Enter 1 for constant fluid velocities. Then, on the next two lines, enter for the two fluids, the X, Y, and Z components of the velocities.

10) Fluid Interface Level:

Enter a 0 for a zero interface level.

Enter a 1 for a nonzero interface level. Then, on the next line, enter a distance.

3. Number of links: Enter number.

4. Individual link data: As follows:

1) Link number
2) Label: Up to 20 characters
3) Link reference point label: Up to 20 characters
4) Link number of adjacent lower numbered link
5) Link weight density (per unit length)
6) Link length
7) Link diameter

8) Initial configuration of the link: Enter γ, α, and β initial angles (in degrees) for three-dimensional analysis. Enter β for two-dimensional analysis.

9) Initial motion of the link: Enter $\dot{\gamma}$, $\dot{\alpha}$, and $\dot{\beta}$ the derivatives of of the initial angles (in degrees/second) for three-dimensional analysis. Enter $\dot{\beta}$ for two-dimensional analysis.

5. Number of towed spheres: Enter number.

6. Individual towed sphere data: As follows:

1) Towed sphere number
2) Towed sphere label (up to 20 characters)
3) Link number of adjacent towing link
4) Towed sphere weight
5) Towed sphere diameter

7. Motion of the mean ship frame and the system reference point: Enter data only for non-zero variables among the following:

Identification Number	Variable
1	Forward displacement of reference point Q relative to the mean ship frame.
2	Starboard displacement of reference point Q relative to the mean ship frame.
3	Vertical (downward) displacement of reference point Q relative to the mean ship frame.
4	Forward speed of the mean ship frame.
5	Turning angle (positive starboard) of the mean ship frame.

Enter the variable identification number in column 1. In column 2 enter: 1 for precoded function; 2 for acceleration profile.

SUMMARY OF INPUT DATA REQUIREMENTS

If a precoded function is selected values of f_0, A, B, p, and ϕ on the subsequent line. (See Equation (16).)

If an acceleration profile is selected, enter the following data lines:

1) Number of points (up to 25)
2) Initial time; Initial acceleration; Initial speed; Initial displacement (all on one line).
3) Time; acceleration (one line for each remaining point).

8. Integration Options: Enter on a single line: i) starting time; ii) ending time; iii) time increment; and iv) error bound.

9. Output Options:
   1) Enter the printing time increment
   2) Enter number from 0 to 4 in column 1 as follows:

   0 - Print all data.
   1 - Print all but tension at the joints.
   2 - Print as above except for tension at the reference point Q.
   3 - Print above except for joint kinematics.
   4 - Print as above except for mass center kinematics.

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This is a User's Manual for the computer program UCIN-CABLE II. The program is designed to study the three-dimensional dynamics and partially submerged towing cables. The cables themselves may have multiple branches.

The manual provides instruction for using CABLE. It provides sample input data. The coding is in FORTRAN.